

# Preliminaries on a proton imaging detector

Van Nguyen

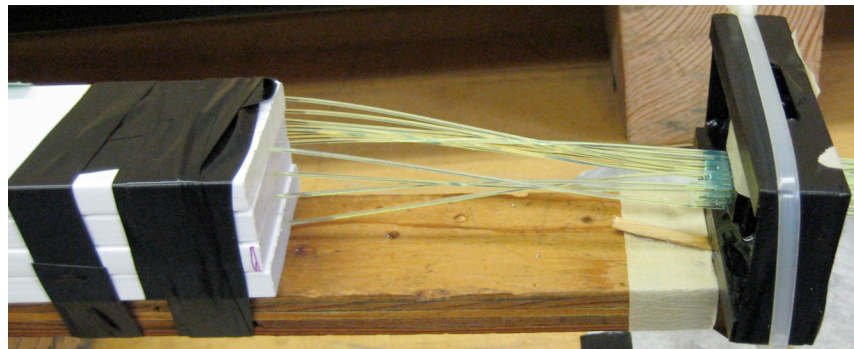
1.30.09

# Outline

- Possible detector design
- Scintillator stopping power

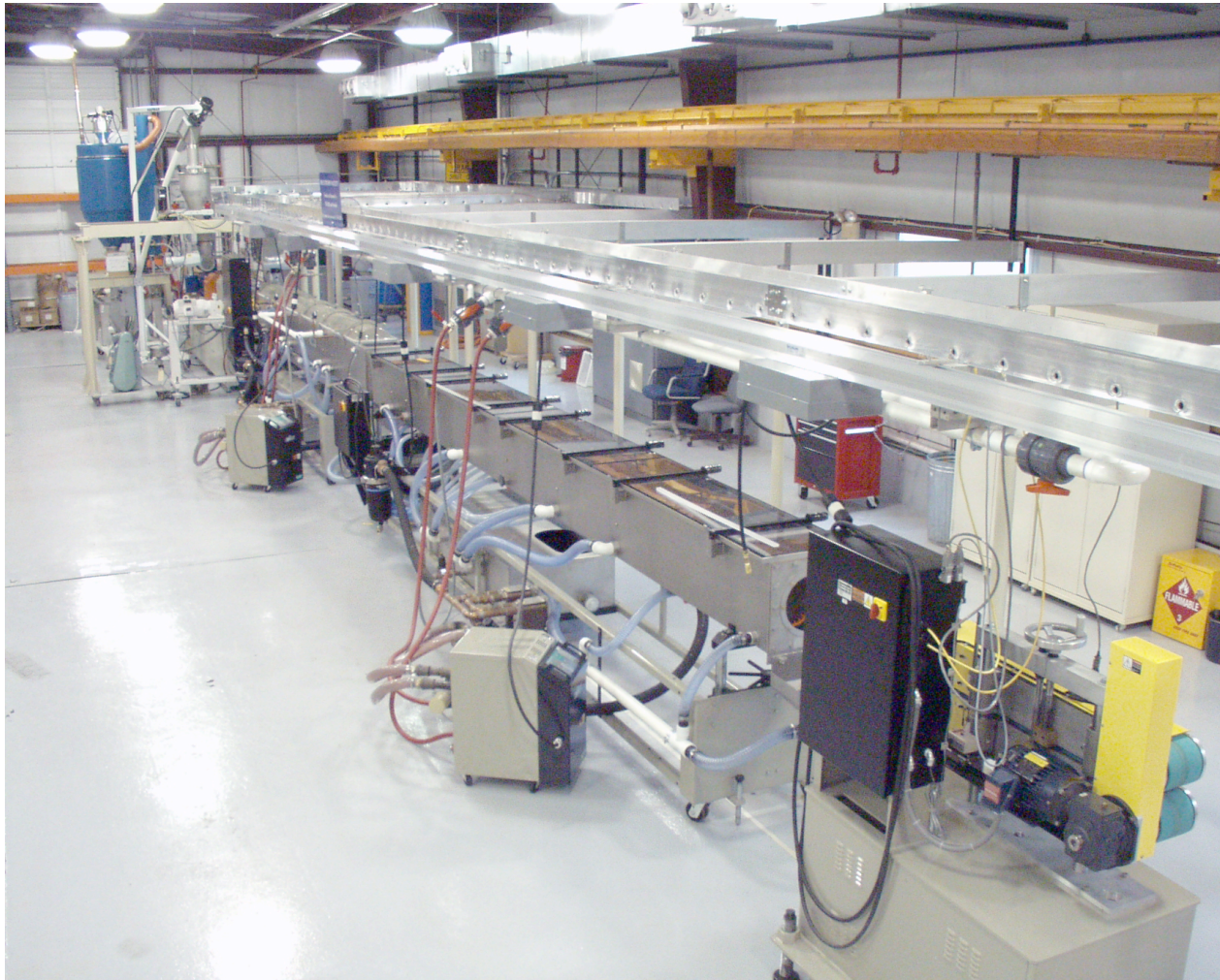
# Double Chooz Outer Veto

- The idea is to create a detector to detect protons entering and exiting the patient to form a radiograph
- We are considering a design very similar to the Double Chooz outer veto.
  - It consists of 4 layers of extruded scintillator strips (1.5m) each containing a WLSF (1.2mm or 1.5 mm diameter). The fibers will be glued into the hole and the ends will be polished with a diamond head
  - The idea is that when a strip is hit by a particle, atoms in the scintillator will be excited. When the atoms de-excite, photons will be emitted and will travel in the scintillator. Some of these photons will be trapped in the WLS fiber and will travel toward a PMT, which collects and converts the light into an electric signal
  - Nevis is developing the electronics - can definitely detect 1/3 pe



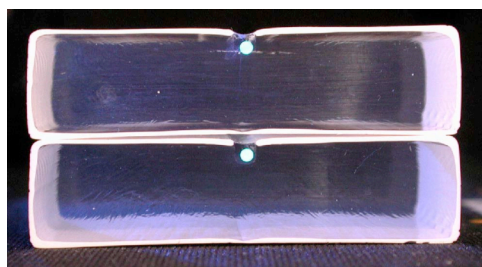
# Extruded scintillator

- Fermilab Extruded Scintillator Facility located in Lab 5 (run by Anna Pla)

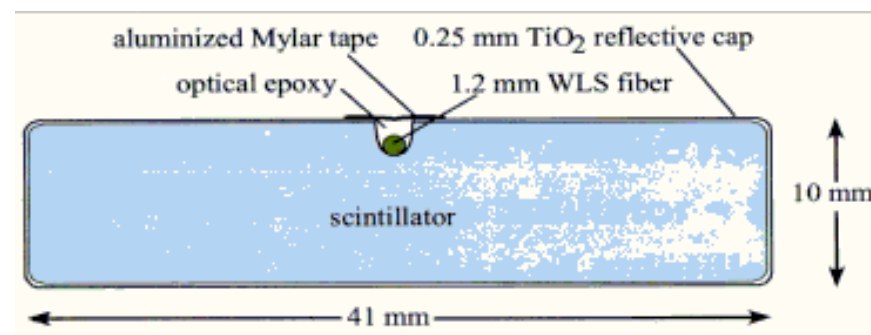


# Extruded scintillator shapes

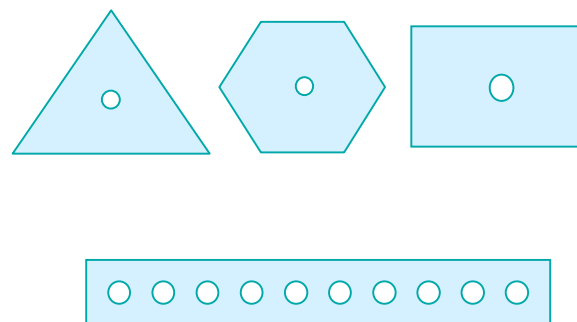
- At the last meeting, we were thinking of rectangular-shaped extruded scintillator of dimensions 3mm x 5mm with a groove for the WLSF
- This would be similar to the Minos extruded scintillator design, shown below



4x1 cm, grooved  
 $\text{TiO}_2$  reflector



- However, for our small size, we would have to purchase a new die, which is \$10k
- The cost estimate for this design is shown on the next page



## EXTRUDED SCINTILLATOR FOR MIT

Prepared by Anna Pla-Dalmau

Date: January 29, 2009

**IMPORTANT: PROJECT WILL BE BILLED AT ACTUAL COSTS. THIS IS AN ESTIMATE.**

Rectangular scintillator bars with titanium dioxide coating with a groove/hole for a WLS fiber: 5 mm x 3 mm

Total amount for prototype: 70 m

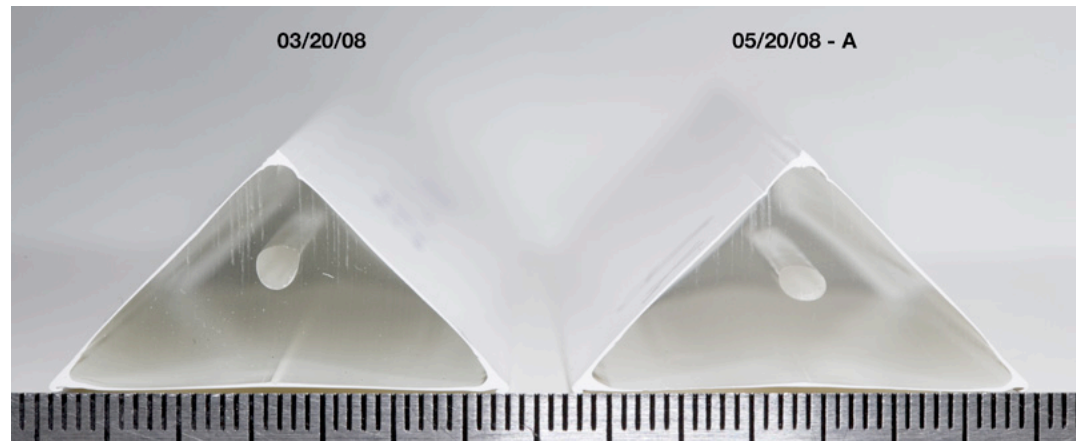
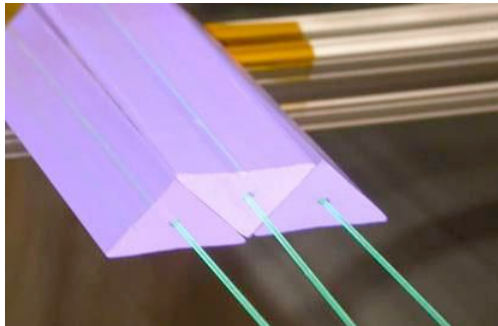
	Estimated Materials and Services Cost (\$)	Estimated Time (hours)	Rate (hours)	Estimated Labor Effort (\$)	Total Estimated Cost Materials and Labor (\$)
<b>Die tuning - Material</b>					
Die	\$10,000.00				
Polystyrene pellets (100 Kg @ \$2.60 each)	\$260.00				
Dopants (3 units @ \$190 each)	\$570.00				
Titanium dioxide pellets (3 Kg @ \$7.30 each)	\$21.90				
Nitrogen gas (4 LN <sub>2</sub> dewars @ \$126 each)	\$252.00				
<b>Die tuning - Labor</b>					
Extrusion preparation and operation		60	\$60.00	\$3,600.00	
Extrusion QC and assistance		80	\$35.00	\$2,800.00	
Project coordination		16	\$65.00	\$1,040.00	
Set-up and tear-down (half-day each, 2 people)		20	\$60.00	\$1,200.00	
<b>Shipping</b>					
Box	\$0.00			\$0.00	
Ship to MIT	\$100.00				
<b>Extrusion equipment maintenance</b>	\$3,000.00				
<b>Estimated Direct Cost</b>	\$14,203.90			\$8,640.00	<b>\$22,843.90</b>
FNAL Indirect Charges (16.03% M&S)	\$2,276.89				<b>\$2,276.89</b>
FNAL Indirect Charges (61.16% Labor)				\$5,284.22	<b>\$5,284.22</b>
<b>TOTAL Estimated Cost</b>	<b>\$16,480.79</b>			<b>\$13,924.22</b>	<b>\$30,405.01</b>

Notes from Anna Pla:

- It is a very small part. It is possible to extrude. We will need to process it at a very slow rate.
  - *The die and its tuning (labor) is the major cost.*
  - I allowed for a full week of tweaking. It is conservative but we don't have a lot of experience dealing with small parts.
  - The 10-cm sections would be cut as a secondary operation since we cannot not deal with these small pieces in the extrusion line. We would probably cut 1 m or 2 m strips for better handling.
  - *I would recommend that you consider extruding a hole instead of a groove.*
  - The groove needs to be pretty large, to cover the 1 mm fiber with glue. A hole may be easier to extrude. *Do you really need to glue the fiber to the scintillator?*
  - I assumed that you would want the white reflective coating.
  - *D0 preshower detector uses a tiny triangle about 5 mm.*
- I have this die. It does not have the co-extrusion ability but it can be added. It could save you some money. This triangle extruded very nicely with a nice hole. Rectangles have a tendency to have oval holes. The triangle shape may offer other characteristics that could be of interest to you.

# Triangular extruded scintillator

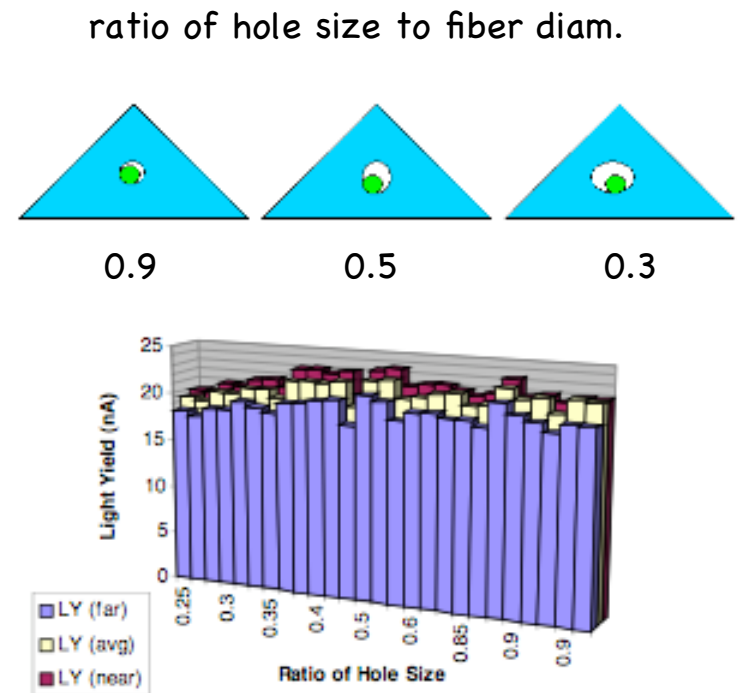
The strips for the MINERvA inner detector have a triangular shape. All strips have a white reflective coating on the outside and a center hole for a wavelength shifting fiber. The position and the size of the hole were designed for easy assembly of the strips into detector modules. Design parameters, including the coating thickness, were assessed for their effect on light yield.



# Fiber hole size

In order to measure if the size of extruded hole would affect the light yield of the scintillator strips, measurements were performed on a sample with a variety of hole sizes. Regardless of the hole size, the same 1.2 mm Kuraray Y11 WLS fiber was used. The resultant light yield using a  $^{137}\text{Cs}$  gamma source was measured.

It was shown that a better match between hole size and fiber diameter does not usually render a higher light yield, i.e. the hole size does not have a significant impact on the light yield.



# Which fiber to use?

From Kuraray:

Minimum 0.2 mm, maximum 2.0 mm diam.

Typical values for round fibers: 0.2, 0.5, 1.0, 1.5, 2.0 mm diam.

Example:

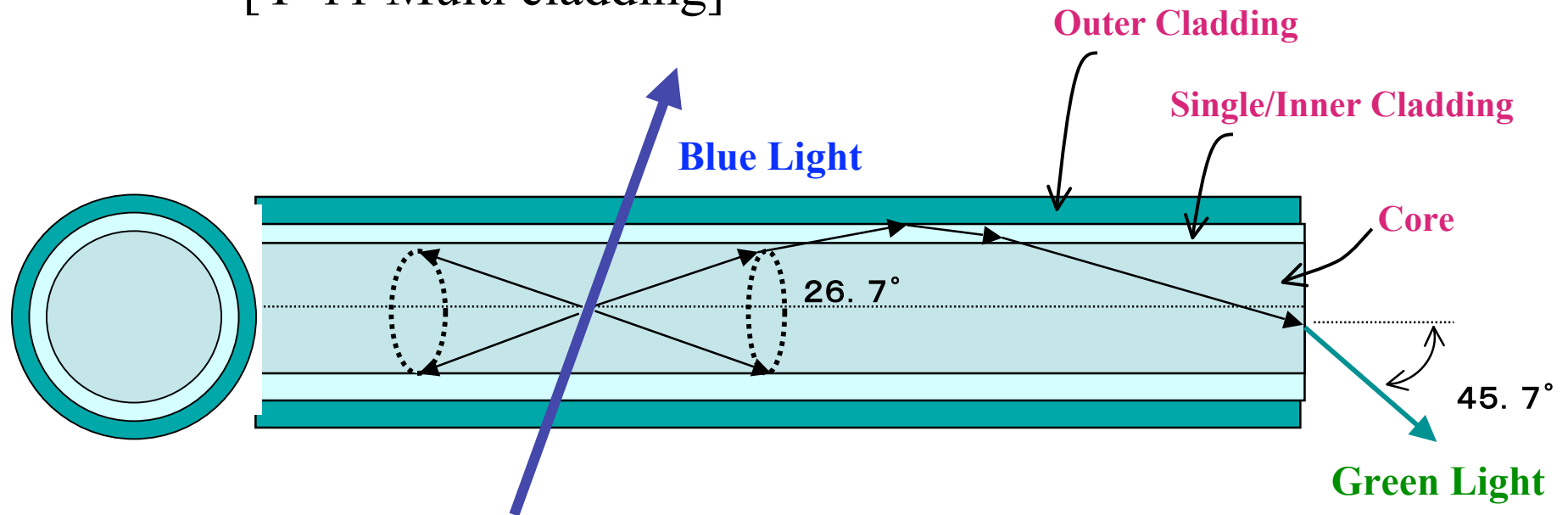
## SciBar detector

- Scintillator Material Polystyrene with PPO(1%) and POPOP(0.03%)
- Size 2.5 × 1.3 × 300 cm
- Coating 0.25 mm (TiO<sub>2</sub>)
- Emission wavelength 420 nm (peak)
- Fiber Type Kuraray Y11(200)M
- Diameter 1.5 mm
- Refractive index 1.59 (outer)/ 1.50 (middle)/ 1.42 (inner)
- Absorption wavelength 430 nm (peak)
- Emission wavelength 476 nm (peak)
- Attenuation length 350 cm

Description	Color	Peak (nm)	Att. Length (m)
Y-7(100), Y-7(100)M	green	490	>3.0
Y-8(100), Y-8(100)M	green	511	>2.8
Y-11(200), Y-11(200)M	green	476	>3.5
O-2(100), O-2(100)M	orange	538	>1.5

# Transmission Mechanism of Multi-Cladding Fiber

[Y-11 Multi cladding]



◆ Multi cladding fiber has 50% higher light yield than single cladding fiber

	Material	Refractive Index	Density (g/cm)
Core	Polystyrene	nD=1.59	1.05
Single/Inner Cladding	Polymethylmethacrylate	nD=1.49	1.19
Outer Cladding	Fluorinated Polymer	nD=1.42	1.43

# Scintillator stopping power



- See <http://physics.nist.gov> (NIST = National Institute of Standards and Technology)
- Click on Physical Reference Data
- Under Radiation Dosimetry Data, click on Stopping-Power and Range Tables for Electrons, Protons, and Helium Ions
- Click on pstar for stopping-power and range tables for protons

**Material:**

1: Hydrogen

☐ **Graph stopping power:**

☐ Total Stopping Power

☐ Electronic Stopping Power

☐ Nuclear Stopping Power

☒ **Graph range:**

☐ CSDA Range

☒ Projected Range

☐ **Graph detour factor**

☐ **No graph**

**Additional Energies (optional):**

Use energies from a file\*

no file selected

or

Use energies entered below (one per line)

☐ Include default energies

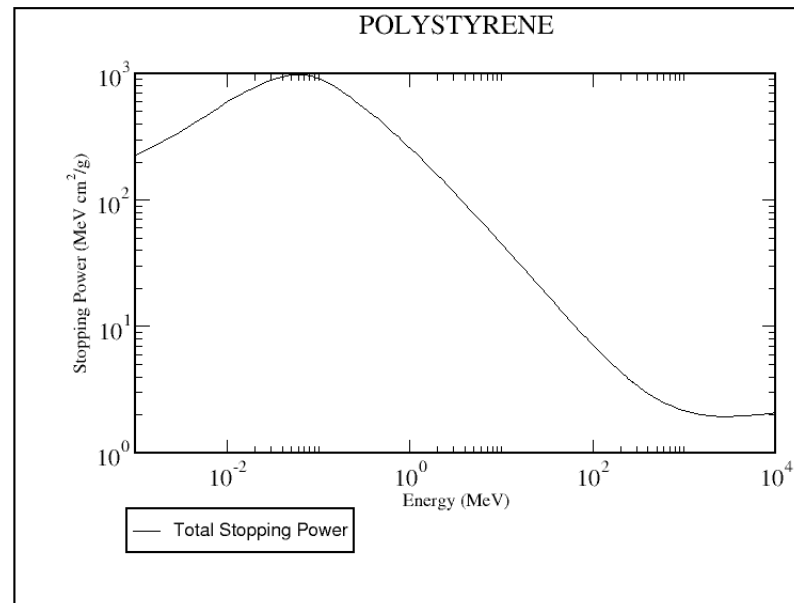
- Under Material composition data, we get the following information for polystyrene

### Composition of POLYSTYRENE:

Density (g/cm<sup>3</sup>) = 1.06000E+00


Mean Excitation Energy (eV) = 68.700000

COMPOSITION:	
Atomic number	Fraction by weight
1	0.077418
6	0.922582



Kinetic Energy (MeV)	Total Stopping Power MeV cm <sup>2</sup> /g	Projected Range g/cm <sup>2</sup>
10	45.00	0.11243
20	25.62	0.4318
30	18.42	0.8989
40	14.60	1.513
50	12.21	2.265
60	10.57	3.147
70	9.369	4.153
80	8.452	5.278
90	7.728	6.515
100	7.140	7.862
110	6.654	9.312
120	6.245	10.86
130	5.896	12.51
140	5.594	14.25
150	5.331	16.08
160	5.099	18.00
170	4.894	20.00
180	4.710	22.08
190	4.546	24.24
200	4.397	26.48
210	4.262	28.78
220	4.138	31.16
230	4.026	36.13
240	3.922	38.71
250	3.827	41.35
260	3.739	44.05
270	3.657	46.81
280	3.581	49.63
290	3.510	52.51
300	3.444	55.43

# Scintillator stopping power cont'd

 ... web driven nuclear science

Input

Details

Compound Details

Options

**Input**

Projectile

Projectile Ion

proton

Energy (MeV)

250

Target

Polystyrene

Density (g/cm<sup>3</sup>)

1.06

☐ Mono-element

☐ Predefined compound

☒ User defined compound

☒ Solid

☐ Gas

Run

**Results**

Projected range, R:

3.950E+2 mm

Mass thickness:

4.187E+1 g/cm<sup>2</sup>

Stopping Power (total):

3.531E+0 keV/(mg/cm<sup>2</sup>)

- See <http://www.nucleonica.net/>
- Nuclear science -> range and stopping power
- Need to add polystyrene to target list (use composition info shown before)

Ion Energy	dE/dx Elec.	dE/dx Nuclear	Projected Range	Longitudinal Straggling	Lateral Straggling
10.00 MeV	4.395E+00	2.146E-03	1.27 mm	57.11 um	34.99 um
11.00 MeV	4.070E+00	1.970E-03	1.51 mm	66.66 um	41.22 um
12.00 MeV	3.794E+00	1.821E-03	1.77 mm	76.27 um	47.90 um
13.00 MeV	3.556E+00	1.694E-03	2.04 mm	86.01 um	55.02 um
14.00 MeV	3.349E+00	1.585E-03	2.33 mm	95.89 um	62.57 um
15.00 MeV	3.167E+00	1.489E-03	2.63 mm	105.93 um	70.54 um
16.00 MeV	3.005E+00	1.405E-03	2.96 mm	116.15 um	78.93 um
17.00 MeV	2.860E+00	1.330E-03	3.30 mm	126.54 um	87.73 um
18.00 MeV	2.731E+00	1.263E-03	3.65 mm	137.10 um	96.94 um
20.00 MeV	2.506E+00	1.148E-03	4.42 mm	176.10 um	116.56 um
22.50 MeV	2.277E+00	1.031E-03	5.46 mm	231.87 um	143.30 um
25.00 MeV	2.090E+00	9.372E-04	6.61 mm	284.85 um	172.42 um
27.50 MeV	1.935E+00	8.594E-04	7.85 mm	336.87 um	203.86 um
30.00 MeV	1.803E+00	7.940E-04	9.19 mm	388.75 um	237.57 um
32.50 MeV	1.690E+00	7.382E-04	10.62 mm	440.88 um	273.50 um
35.00 MeV	1.591E+00	6.900E-04	12.14 mm	493.51 um	311.60 um
37.50 MeV	1.505E+00	6.480E-04	13.75 mm	546.76 um	351.83 um
40.00 MeV	1.429E+00	6.109E-04	15.45 mm	600.71 um	394.13 um
45.00 MeV	1.300E+00	5.486E-04	19.12 mm	799.35 um	484.86 um
50.00 MeV	1.196E+00	4.983E-04	23.12 mm	986.13 um	583.47 um
55.00 MeV	1.109E+00	4.567E-04	27.46 mm	1.17 mm	689.69 um
60.00 MeV	1.035E+00	4.217E-04	32.12 mm	1.35 mm	803.27 um
65.00 MeV	9.722E-01	3.919E-04	37.10 mm	1.53 mm	923.96 um
70.00 MeV	9.177E-01	3.662E-04	42.39 mm	1.71 mm	1.05 mm
80.00 MeV	8.279E-01	3.240E-04	53.84 mm	2.37 mm	1.33 mm
90.00 MeV	7.570E-01	2.908E-04	66.46 mm	2.99 mm	1.63 mm
100.00 MeV	6.994E-01	2.640E-04	80.19 mm	3.58 mm	1.95 mm
110.00 MeV	6.518E-01	2.418E-04	94.98 mm	4.17 mm	2.30 mm
120.00 MeV	6.117E-01	2.232E-04	110.80 mm	4.75 mm	2.67 mm
130.00 MeV	5.774E-01	2.074E-04	127.61 mm	5.33 mm	3.05 mm
140.00 MeV	5.478E-01	1.937E-04	145.37 mm	5.92 mm	3.46 mm
150.00 MeV	5.220E-01	1.818E-04	164.05 mm	6.51 mm	3.89 mm
160.00 MeV	4.993E-01	1.713E-04	183.61 mm	7.10 mm	4.33 mm
170.00 MeV	4.791E-01	1.620E-04	204.04 mm	7.70 mm	4.79 mm
180.00 MeV	4.611E-01	1.536E-04	225.29 mm	8.29 mm	5.27 mm
200.00 MeV	4.303E-01	1.394E-04	270.15 mm	10.50 mm	6.26 mm
225.00 MeV	3.992E-01	1.250E-04	330.41 mm	13.59 mm	7.58 mm
250.00 MeV	3.742E-01	1.134E-04	395.03 mm	16.45 mm	8.98 mm
275.00 MeV	3.537E-01	1.039E-04	463.69 mm	19.17 mm	10.44 mm
300.00 MeV	3.365E-01	9.583E-05	536.09 mm	21.82 mm	11.97 mm
325.00 MeV	3.219E-01	8.898E-05	611.97 mm	24.39 mm	13.55 mm
350.00 MeV	3.095E-01	8.308E-05	691.10 mm	26.92 mm	15.17 mm